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SUMMARY

Some experimental results are presented from wind-tunnel studies of a dynamic model equipped with an aeromechanical gust-alleviation system for reducing the normal acceleration response of light airplanes. The system uses two auxiliary aerodynamic surfaces mounted on the fuselage below the wing. Each surface is hinged about a chordwise axis to change its dihedral angle in response to gusts. As the auxiliary surface dihedral changes, the flaps on the wing are driven by interconnecting linkages so as to maintain nearly constant lift on the wing. The gust-alleviation system was implemented on a 1/6-scale, rod-mounted, free-flying model that is geometrically and dynamically representative of small, four-place, high-wing, single-engine, light airplanes. The model was tested at the scaled cruise velocity in the Langley transonic dynamics tunnel using gust-generating vanes. The vanes generated sinusoidal vertical gusts of slowly varying frequency in the test section where the model was mounted with vertical and pitch degrees of freedom. Flaps with different spans, two different sizes of the auxiliary surfaces, plain and double-hinged flaps, and a flap-elevator interconnection were tested. The model test results are presented in terms of predicted full scale airplane root-mean-square response to atmospheric turbulence. In comparison with the flaps-locked condition, certain configurations achieved a reduction of 30 percent in the root-mean-square normal acceleration response with the system active. In addition, a slight reduction in the pitching-rate response was achieved. Because the hinges of the gust-alleviation system had an inordinate amount of friction that slowed and limited the response of the flaps, reducing the friction would probably increase the alleviation substantially over the 30 percent achieved.

INTRODUCTION

A relatively simple aeromechanical gust-alleviation system for light airplanes has been under study at the NASA Langley Research Center. This work has included both theoretical studies and wind-tunnel tests of a dynamic model. (See refs. 1 to 4.) The gust-alleviation system consists of a pair of auxiliary aerodynamic surfaces (vanes) mounted below the wing on the fuselage. The vanes are mechanically connected to the wing flaps. They are hinged about chordwise axes so that they can change their dihedral angle. When the airplane encounters a gust, the incremental lift on the vanes causes the vane dihedral angles to change. As the vane dihedral angle changes, the mechanical linkages force the flaps to rotate. The magnitude of the flap rotation is such that the wing lift is changed to compensate for the increase in lift caused by the gust. Therefore, when gusts are encountered, the total airplane lift remains relatively constant, and the vertical accelerations of the airplane are reduced.

Previous wind-tunnel studies of a simple system with inboard flaps (ref. 2) have shown only a 30-percent reduction in normal acceleration. Furthermore, that system produced a significant increase in the model pitching response.

This response would probably negate some of the improvement in ride quality achieved by reducing the normal acceleration response. However, theoretical studies (refs. 1 and 4) have indicated that modification of the system should make a larger reduction in normal acceleration response possible and should improve the pitching characteristics. Hence, some additional wind-tunnel tests of the model have been made. The tests included several different trailing-edge flap systems as well as other variations in the previously tested system. This paper presents the results from these latest tests.

The wind-tunnel tests were conducted in the Langley transonic dynamics tunnel using a 1/6-scale model that was dynamically and geometrically representative of a four-place, high-wing, single-engine, light airplane. The model was equipped with the aeromechanical gust-alleviation system and was tested in a sinusoidally oscillating vertical gust field. The gust-alleviation system (i.e., vanes, flaps, etc.) used in reference 2 was modified for the present tests. The tunnel, the basic airplane model, the testing technique, and the data reduction methods were essentially the same. (See ref. 2 for a more complete discussion of these factors.) Parameters studied during the present tests included flap span, plain and double-hinged flaps, a flap-elevator interconnection, and vane size. The data are presented in terms of root-mean-square (rms) response of a full scale airplane in atmospheric turbulence as predicted from the experimental results. These data are compared qualitatively with the analytical results from references 1 and 4.

SYMBOLS

b_f flap span, m

b_v vane span, m

C_h hinge-moment coefficient, $\dfrac{H}{\frac{1}{2}\rho V^2 S_f c_f}$

$C_{h_{\delta_f}}$ partial derivative of hinge-moment coefficient with respect to flap deflection, $\dfrac{\partial C_h}{\partial \delta_f}$

C_L lift coefficient, $\dfrac{L}{\frac{1}{2}\rho V^2 S}$

C_{L_α} partial derivative of lift coefficient with respect to angle of attack, $\dfrac{\partial C_L}{\partial \alpha}$

$C_{L_{\delta_f}}$ partial derivative of lift coefficient with respect to flap deflection, $\dfrac{\partial C_L}{\partial \delta_f}$

C_m	pitching-moment coefficient, $\frac{M}{\frac{1}{2}\rho V^2 Sc}$
$\left(C_{m_{\delta_f}}\right)_w$	partial derivative of pitching-moment coefficient with respect to flap deflection (wing-fuselage component only, excluding pitching moment due to flap downwash on tail), $\left(\frac{\partial C_m}{\partial \delta_f}\right)_{wing\text{-}fuselage}$
c	mean aerodynamic chord of wing, m
c_f	chord of flap, m
g	acceleration of gravity, 9.80 m/sec^2
H	hinge moment about flap axis, N-m
I	moment of inertia of combined flap-vane system as measured about flap-rotation axis, $I_f + \gamma^2 I_v$, kg-m^2
I_f	moment of inertia of flaps about flap rotation axis, kg-m^2
I_v	moment of inertia of vanes about vane dihedral hinge axes, kg-m^2
I_Y	moment of inertia of model about Y-axis, kg-m^2
K	flap gain, equal to negative of ratio of flap-deflection change to angle-of-attack change, $\frac{-\Delta\delta_f}{\Delta\alpha}$
K_v	vertical static alleviation factor
L	lift, N
M	pitching moment, N-m
m	mass of airplane, kg
S	area of wing, m^2
S_f	area of flap, m^2
V	true velocity with respect to undisturbed air mass, m/sec
X,Y,Z	coordinate axes
α	angle of attack, rad or deg

γ gearing ratio, $\frac{\Delta\delta_v}{\Delta\delta_f}$

δ_f deflection of leading half of flap, positive when trailing edge is down, rad or deg

δ_v vane dihedral deflection angle, positive when outboard end is down, rad or deg

ε downwash angle at horizontal tail, positive downward, rad

ζ_f flap-vane damping ratio

ρ density of air, 1.226 kg/m^2

σ_n root-mean-square normal acceleration response, g units

σ_q root-mean-square pitch rate response, deg/sec

σ_{wg} root-mean-square vertical gust velocity, m/sec

$\omega_{n,f}$ flap-vane natural frequency, rad/sec

$\frac{\partial\varepsilon}{\partial\delta_f}$ change in downwash at horizontal tail with respect to flap deflection

GENERAL DESCRIPTION OF GUST-ALLEVIATION SYSTEM

A schematic representation of the gust-alleviation system is shown in figure 1. The gust-alleviation system uses two auxiliary aerodynamic surfaces to drive the flaps and reduce the vertical response to vertical gusts. A complete description of the action of the system and its components is given in references 1, 2, and 3.

TEST EQUIPMENT

Wind Tunnel

The wind-tunnel tests were conducted in the Langley transonic dynamics tunnel (TDT). The TDT is a single-return tunnel powered by a motor-driven fan. The tunnel test section is 4.88 meters square with cropped corners.

The tunnel is equipped with a gust-generating system (ref. 5), that produces nearly sinusoidal variations in the vertical velocity of the air flow in the test section. These variations produce sinusoidal oscillations of the gust angle of attack at the model. At the tunnel test conditions used, the amplitude of this gust angle of attack varied from about 0.3° at an oscillation frequency of 5.0 Hz to 2.0° at an oscillation frequency of 0.5 Hz.

Dynamic Model

General description.- The model was a simplified 1/6-scale, rod-mounted, free-flying model that is geometrically and dynamically representative of a small, single-engine, four-place, high-wing, light airplane; this model is the one used in reference 2. The model-to-airplane scale factors for Froude number scaling are presented in table I. Also included in table I is a comparison of model and airplane inertia properties. The mass of the model was approximately the desired airplane scaled value, but the pitch moment of inertia I_Y was too large by almost 50 percent. Although the model was not in perfect scale, the model responses are considered representative of a full scale, light airplane with the system installed. A photograph of the model mounted in the tunnel is shown in figure 2.

Gust-alleviation system.- The geometry of the gust-alleviation system is presented in a three-view drawing of the model in figure 3. Notice that the loading spring and the elevator-vane incidence interconnection (shown in fig. 1 and needed on the full scale airplane) were not implemented on the model because they do not directly influence the vertical gust responses studied in these tests.

Vanes: The details of the vanes are shown in figure 4. Each vane consisted of three different sections; inboard, middle, and outboard. The inboard section was rigidly attached to the fuselage and provided only structural support for the two movable sections. The middle section was hinged about a chordwise axis to permit changes in dihedral angle only. A balance weight was part of this middle section and provided dihedral balance for both the middle and outboard sections.

The outboard section of the vane had freedom to change both dihedral and incidence angles. It was attached to the incidence pivot shaft (spanwise axis) by a set screw so that it could be easily removed and replaced with a different size panel without disturbing the linkage or flap. Two panel sizes were used. A photograph of the vane with the moving sections displaced is shown in figure 5.

Flaps: The flaps were divided into three spanwise sections which could be actuated individually or together in any combination (see figs. 6 and 7). The two inboard sections of the flap (in place of the standard flap on the full scale airplane) were mounted on a torque tube, and the outboard section (in the place of the aileron) was mounted on two small hinges. The two inboard sections were attached to the torque tube with set screws which could be loosened, if desired, to allow the torque tube to turn without moving the flap sections. The outboard section of flap was hinged at an angle with respect to the two inboard sections because the outboard section of the wing was tapered. (See fig. 3.) The outboard section of the flap was, therefore, driven by a ball in a slot to compensate for the angular difference (see figs. 6 and 7). This arrangement resulted in a rotation of about 1.9° by the outboard section for each degree of rotation of the torque tube. The ball was mounted on a drive arm attached to the torque tube. The outboard flap section could, therefore, be deactivated by simply loosening a set screw in the drive arm to allow the torque tube to turn inside the drive arm.

Each spanwise flap section had two separate fore and aft sections. The aft section was hinged about an axis in the fore section so that it rotated with respect to the leading section as shown in figures 6 and 8. This compound, double-hinged arrangement is referred to as "articulation" in this paper. The geometry of the articulation mechanism was such that the angle between the fore and aft sections was approximately 0.9 of the angle between the leading section and the wing. The angle of the leading section of the flap (equal to the rotation of the torque tube) is defined as δ_f. The change in wing camber as the flap deflected was thus made more gradual with articulation than with a plain flap. The mechanism could be disconnected easily to revert to the plain flap configuration.

The flap torque tube was driven by an arm attached to the vane-flap linkage. The arm was inside a hole in the wing located forward of the flap and the torque tube. The linkage attachment point on the arm could be adjusted to provide moment arms of different lengths for different flap-vane gearing ratios. The length of the moment arm could be varied to provide a range of flap-vane gearing ratio γ of 0.4 to 1.7.

The total moment of inertia about the flap axis is shown in figure 9. The total inertias include both the basic flap inertia and the vane inertia reflected back to the flap axis. In general, the measured inertia was larger than the inertia estimated in reference 3 and smaller than the calculated values based on an unpublished engineering design estimate. (The total inertia I about the flap axis was shown to be equal to $I_f + \gamma^2 I_v$ in ref. 1.)

Elevator: The elevator was composed of the main elevator and two mini-elevator surfaces which could be connected directly to the flaps with linkage rods. (See fig. 10.) With the linkages connected, the trailing edges of both the flaps and the mini-elevator move down together. The main elevator could be independently deflected to provide pitch trim control.

Mounting system.- The model was mounted in the tunnel using the system described in reference 2. This mounting system provided about 3 m of vertical travel, about 30° of pitch rotation, and unlimited freedom in yaw. Actually, very little yaw freedom was needed because of the directional stability of the model.

Controls.- The model was equipped with several different features for remotely controlling and trimming the model at the desired test conditions, as described in reference 2. A servo-controlled elevator was used for trimming the model in pitch; a motor-driven screw was used to control vane incidence for trimming the flap. The control commands to these systems were sent from a small panel operated manually by a "pilot" in the tunnel control room who observed the model's condition. These pilot commands were sent as electrical signals through a multi-conductor cable 1 cm in diameter.

PROCEDURE

Wind-Tunnel Tests

Test conditions.- The tunnel was run using air at ambient atmospheric pressure and density. The wind velocity through the tunnel test section was held constant at approximately 22 m/sec. This velocity was required for Froude number scaling at simulated cruise conditions. The Reynolds number at the desired test condition was 0.37×10^6 based on the model wing chord.

Types of tests.- The two types of tests were (1) tests of the quasi-static flap response to determine the flap gain and (2) tests of the model response to sinusoidal gusts of slowly decreasing frequency and slowly increasing amplitude to determine the dynamic effectiveness of the gust-alleviation system.

Experimental variables.- The variables studied experimentally were flap span, flap articulation, vane size, and the interconnection of flap and mini-elevator. The selection of these variables was based on the analytical studies presented in references 1 and 4. In reference 1, alleviation was shown to be a function of the flap-vane system natural frequency; the larger the frequency, the greater the alleviation. If the flap inertia is small in comparison to the vane inertia and if the static flap gain (the amount of static alleviation) is held constant, the natural frequency is given by the proportionality

$$\omega_{n,f} \propto C_{L_{\delta_f}} \sqrt{\frac{b_v b_f}{C_{h_{\delta_f}} c_f}} \tag{1}$$

Thus, an effective flap $\left(\text{large } C_{L_{\delta_f}}\right)$ with a long span (large b_f) and low hinge moment $\left(\text{small } C_{h_{\delta_f}}\right)$ should produce good alleviation.

It was also shown in reference 4 that the alleviation could be increased and the pitching response reduced either by reducing the flap downwash on the horizontal tail $\frac{\partial \varepsilon}{\partial \delta_f}$ or by making the flap pitching moment $\left(C_{m_{\delta_f}}\right)_w$ more negative. The mid-span flap should reduce $\frac{\partial \varepsilon}{\partial \delta_f}$ not only because this flap has a smaller area than that of the nominal-span flap but also because it develops a trailing vortex off the inboard end, thus causing an upwash at the inboard section of the tail. The effective flap pitching moment $\left(C_{m_{\delta_f}}\right)_w$ is made more negative by connecting the flaps to the mini-elevator so that both trailing edges move down together.

The combinations of variables investigated are shown in figure 11 where flap span, vane size, and flap articulation are portrayed on a set of three mutually orthogonal axes. The combinations chosen seemed to be the most practical combinations for implementation on a full scale airplane. Three different flap span configurations were tested on the model. The "nominal-span" flap was approximately the same size as the flap on the unmodified full scale airplane and was located at the same position. The "mid-span" flap was the nominal-

span flap with the small, extreme inboard section fixed (this fixed section had an area equal to 20 percent of the area of the nominal-span flap). The "full-span" flap consisted of the nominal-span flap and the outboard flap.

Data Reduction

The data reduction procedure was the same as that described in reference 2. The model gust response measurements at a given frequency were divided by the known gust angles in the TDT and multiplied by the one-dimensional von Kármán gust spectrum for vertical atmospheric turbulence. Similar calculations at other frequencies were multiplied by the appropriate model-to-airplane scale factors and were then integrated over the entire test frequency range to predict the root-mean-square (rms) airplane responses to a vertical gust velocity of 1 m/sec rms.

RESULTS AND DISCUSSION

Effect of Flap Span (Using Articulation)

Quasi-static flap response.- A typical quasi-static flap response, variation of flap angle with pitch angle (angle of attack), is shown in figure 12. The hysteresis in the data is probably caused by friction in the hinges and linkages. The nearly linear slope of the plot indicates that, at least quasi-statically, the system operated in a linear aerodynamic region.

The negative of the mean slope of the data is the flap gain K. The reduction in the lift-curve slope and thus the level of static alleviation is directly proportional to the flap gain. The actual level of static alleviation is measured by the vertical static alleviation factor K_V. K_V is 0 for no alleviation and 1.0 for full alleviation (i.e., an effective lift-curve slope of 0 on the alleviated airplane). The following formula gives the vertical static alleviation factor in terms of the flap gain and the aerodynamic derivatives for the unalleviated airplane:

$$K_V = K\left(C_{L_{\delta_f}}/C_{L_\alpha}\right) \tag{2}$$

The level of dynamic alleviation in gusts is determined by K_V and the flap response characteristics $\omega_{n,f}$ and ζ_f.

The flap gain for all tested conditions was calculated from plots similar to that in figure 12. The flap gain as a function of flap-vane gearing ratio for the three flap span conditions is presented in figure 13. For a given gearing ratio, K increases as the flap span is reduced because of the reduced hinge moment due to flap deflection.

Normal acceleration response.- The experimentally predicted normalized rms normal acceleration for a von Kármán gust spectrum is shown in figure 14. The alleviation (reduction in response) obtained for the different flap span configurations is practically the same for each except that the nominal-span

flap may have slightly less alleviation than the other two configurations. The maximum alleviation achieved with any configuration was about 30 percent. This level of alleviation is equal to that attained in the previous study (ref. 2) which used nonarticulated, nominal-span flaps. The present tests would probably have produced more alleviation if the friction level had been as low as the friction in the previous study (ref. 2).

The flaps did not respond to the gusts until the gust amplitude reached a relatively high level although the model itself responded at much lower gust amplitudes. When the flaps did respond, the flap motion was not smooth but showed irregular starts and stops. (For example, see fig. 15(a).) This irregular motion was a result of the friction in the gust-alleviation system. This type of motion was not apparent in the previous tests (see fig. 15(b)); consequently, it is believed that the friction level was considerably lower in those tests.

After the dynamic tests were completed, a few measurements of the torque due to breakout friction were made. The results of these measurements are presented in table II. An estimated gust disturbance of up to 1.2° would be required to overcome these breakout torque levels. This level is considered excessive because the gust angles produced by the TDT gust-generating vanes were usually less than 1.2°. Of course, motion friction such as viscous or coulombic friction would probably affect these dynamic tests more than the static breakout friction measured in the tests described here. Breakout friction is the torque required to start the flap motion and is usually larger than the motion friction. These static measurements, however, do give an indication of the order of the magnitude of the motion friction problem.

With this level of friction, the reduction of the normal acceleration response (alleviation) was probably less than that which could be obtained with lower levels of friction. That is, the friction slowed the flap response and this slowing might be compared to a reduction in the flap-vane natural frequency. As discussed earlier, a reduction in the flap-vane natural frequency results in a reduction in the amount of alleviation attained. Comparison of the results from different configurations, however, should indicate the relative merits of the configurations because each one had a high level of friction.

Another reason for considering only the relative merits of the different configurations in these tests was the mounting system. At the conclusion of these tests, it was discovered that one of the guides in the system had not been installed. The mounting rod was, therefore, in contact with the metal housing in the mount, and this contact caused some increase in friction in the vertical translational degree of freedom. However, these tests were primarily for comparison of different control surfaces. This shift in the friction level, therefore, is not considered significant because it affected all vertical response measurements equally.

Pitch rate response.- The rms pitch rate responses are presented in figure 16. The rms pitch rate for the nominal-span flap was greater than that for the flaps fixed (unalleviated model), especially at the higher gearing ratios where the alleviation of the normal acceleration was the greatest. This result is consistent with that of reference 2.

The other two flap span configurations generally had less pitching response than the unalleviated model. The full-span flap is slightly superior to the mid-span flap in this respect. The mid-span flap probably pitched less because of a reduction in the flap downwash on the horizontal tail. In the same manner, the full-span flap caused a relative decrease in the flap downwash for a given change in pitching moment due to change in wing camber as the flap deflected. This relative change could be considered either as a decrease in the flap downwash or as an increase in the magnitude of the negative flap pitching moment. Both of these changes have been shown theoretically to reduce the pitching response. (See ref. 4.)

Effect of Articulation

Quasi-static flap response.- The effect of articulation on the flap gain is presented in figure 17. The flap gain K without articulation is greater than K with articulation, probably because articulation increases the flap hinge moment due to flap deflection. It should be realized that the effective flap deflection is about 50 percent greater with articulation than without articulation because δ_f is defined as the rotation of the forward section of the flap only. The change in lift with flap deflection $C_{L_{\delta_f}}$ for configurations with articulation should, therefore, be larger than for configurations without articulation. The larger $C_{L_{\delta_f}}$ results in a larger vertical static alleviation factor K_v for a given flap gain (eq. (2)). The difference in the vertical static alleviation factor, which is more fundamental than the flap gain in determining the level of alleviation, thus is not as large as might be inferred from figure 17.

Normal acceleration response.- The rms normal acceleration response with and without articulation is shown in figure 18. The alleviation (reduction in response) attained without articulation for the lower gearing ratios (below about 0.8) is more than the alleviation with articulation, whereas for higher gearing ratios (above 0.8), the opposite is true. The optimum gearing ratio for maximum alleviation for the nominal-span flap without articulation is about 0.6 or less, which agrees well with results in reference 2 for a similar configuration. The optimum gearing ratio for maximum alleviation for either articulated configuration does not appear to have been reached at the largest gearing ratios tested. However, the alleviation at the largest gearing ratio with articulation was greater than the alleviation achieved for the optimum gearing ratio without articulation.

Larger gearing ratios were not tested because the flaps became very difficult to trim due to the increased sensitivity to small changes in angle of attack. This difficulty occurred largely because of the crude mechanism for trimming the flap; the full scale airplane should be easier to trim. Larger gearing ratios probably would not have increased the alleviation significantly in any case because full static alleviation was probably being approached for the gearing ratios already tested.

There are counteracting characteristics which determine the amount of alleviation which can be achieved with and without articulated flaps. Articulated flaps should be more effective $\left(\text{larger } C_{L_{\delta_f}}\right)$, and this characteristic should increase the alleviation (eq. (1)). However, articulated flaps should also have a larger hinge moment $C_{h_{\delta_f}}$, a larger reflected moment of inertia, and greater friction because of the additional motion of the aft section of the flap. These last three characteristics should slow the flap response (or reduce the flap natural frequency, see eq. (1)) and should, therefore, reduce the alleviation which can be achieved. In these tests, the beneficial effect of the increased effectiveness evidently outweighs the detrimental effects of the increase in hinge moment, inertia, and friction because the articulated configurations achieved the most alleviation.

It could be argued that these tests indicate that a much higher level of alleviation would have been achieved if the friction had been at the same level as that which was evidently obtained in reference 2. Thirty-percent normal acceleration alleviation was obtained in those tests for the nominal-span flap without articulation while only 13 percent was achieved in the present tests for a similar configuration. If this difference is assumed to result entirely from friction, the nearly 30-percent alleviation obtained in the present tests for the articulated configurations would extrapolate to nearly 70-percent alleviation in the absence of excessive friction. Although this exact figure is questionable, some increase in alleviation should be expected if the friction were reduced. Additional tests are needed to determine the actual alleviation obtainable under more ideal conditions.

Pitch rate response.- A comparison of the rms pitching rates with and without articulation is shown in figure 19. These data show no consistent, obvious effect of articulation on the pitch rate response.

Use of Mini-Elevator Interconnection

Only one configuration (nominal-span flap with articulation, gearing ratio of 1.05) was tested using the mini-elevator. In the following table the results of those measurements are compared with a similar configuration without the mini-elevator:

Response	Without interconnection	With interconnection
K	2.46	2.74
σ_n/σ_{wg}, g/m/sec	.0468	.0391
σ_q/σ_{wg}, deg/sec/m/sec	1.28	.963

Surprisingly, the value of K with the interconnection is larger than without the interconnection. It was expected that the effective hinge-moment

coefficient $C_{h_{\delta_f}}$ would be increased by adding the mini-elevator hinge moment. The probable reason for the difference is the low accuracy of the measurements. However, the wing-flap downwash on the horizontal tail and mini-elevator could actually lower the effective $C_{h_{\delta_f}}$.

The mini-elevator reduced both the rms normal acceleration and pitching responses as predicted in reference 4. The reduction seems to be real although whether the difference is worth the additional mechanical complexity in implementing this system is questionable.

CONCLUDING REMARKS

The maximum level of normal acceleration alleviation attained in these tests was 30 percent or the same as that achieved in reference 2 with a simpler configuration. However, higher levels of alleviation would probably have been attained in the present tests if the level of mechanical friction were reduced to the level that apparently existed in previous tests. Additional tests are needed to determine the exact amount of alleviation possible. Although the normal acceleration response was not reduced as much as expected, the pitching response was reduced - to a level below even the unalleviated condition. The pitching responses obtained in the previous tests were much larger for the alleviated conditions than for the unalleviated conditions.

Flap span had the predicted effect on the gust responses. Full-span and mid-span flaps seemed to have lower normal acceleration and pitching responses than the nominal-span flap.

Articulation of the flaps increased the effective hinge moment and thus reduced the normal acceleration alleviation for low flap-vane gearing ratios. At higher gearing ratios articulation provided more alleviation than was obtained for the plain flaps with their optimum gearing ratio.

The interconnection between flap and mini-elevator, as expected, reduced both the normal acceleration and pitching responses.

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TABLE I.- MODEL SCALING CHARACTERISTICS

[Geometric scale factor is $\lambda = 1/6$]

(a) Model characteristics and test velocity

Parameter	Scale factor formula	Nominal factor	Model value	Airplane (scaled to model size)
m, kg	λ^3	0.00463	5.65	4.83
I_Y, kg-m^2	λ^5	.000129	.34	.23
V, m/sec	$\lambda^{1/2}$	.408	22.0	[a]22.0

(b) Model response scale factors

Parameter	Scale factor formula	Numerical factor
Time, sec	$\lambda^{1/2}$	0.408
Frequency, Hz	$\lambda^{-1/2}$	2.45
Pitch angle, rad	1.0	1.0
Pitch rate, rad/sec	$\lambda^{-1/2}$	2.45
Flap angle, rad	1.0	1.0
Normal acceleration, g units	1.0	1.0

[a]Approximate cruise velocity.

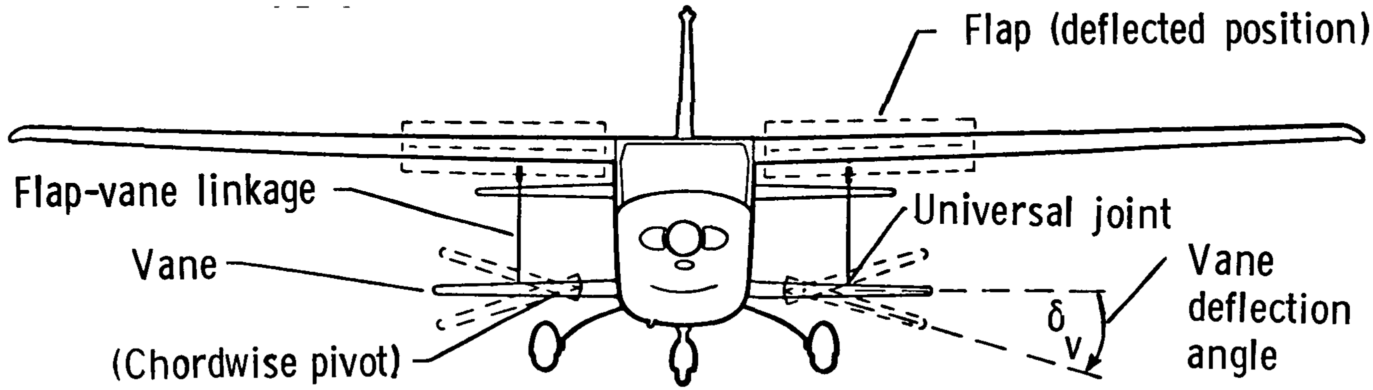
TABLE II.- MEASURED BREAKOUT FRICTION IN FLAP-VANE SYSTEM

[Gearing ratio = 0.92]

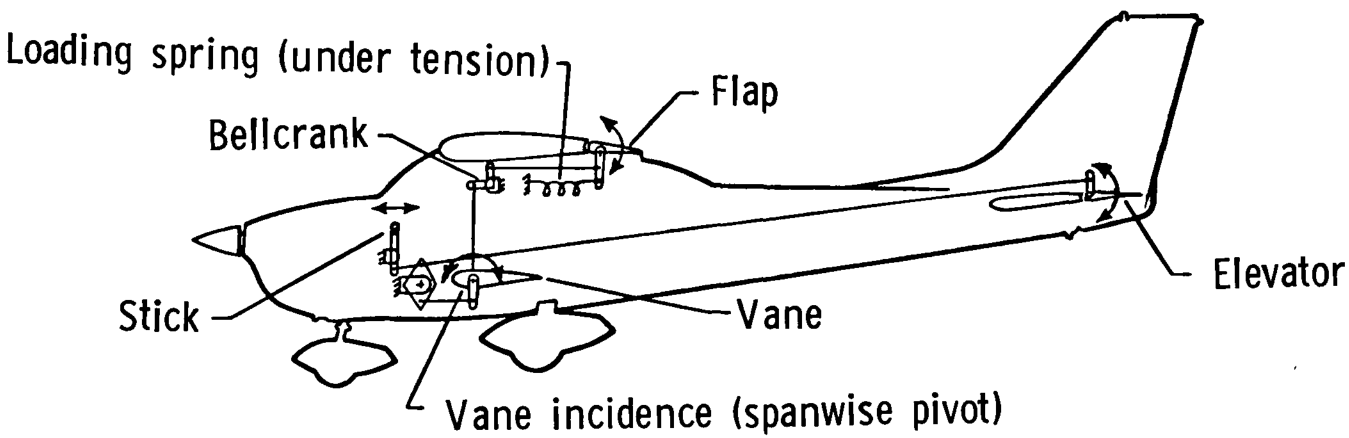
Span	Articulation	Mini-elevator	Measured torque, cm-N	Full scale torque, cm-N	$\Delta\delta_f$, deg (a)	$\Delta\alpha$, deg (b)
Nominal	Yes	No	1.90	2460	1.9	0.6
Full	Yes	No	3.69	4780	3.6	1.2
Nominal	Yes	Yes	2.45	3170	2.4	.8
Mid	Yes	No	1.21	1560	1.2	.4
Mid	No	No	.79	1030	.8	.3
Nominal	No	No	1.48	1920	1.5	.5

[a]Estimated flap deflection required for the aerodynamic hinge moment $\left(\frac{1}{2}\rho V S_f c_f C_{h_{\delta_f}} \Delta\delta_f\right)$ to overcome the breakout friction.

[b]Assuming $K = -\frac{\Delta\delta_f}{\Delta\alpha} = 3$.



(a) Front view (flaps and vanes shown in deflected positions by dotted lines).



(b) Side view (flap and vane shown in neutral position).

Figure 1.- Schematic representation of gust-alleviation system.

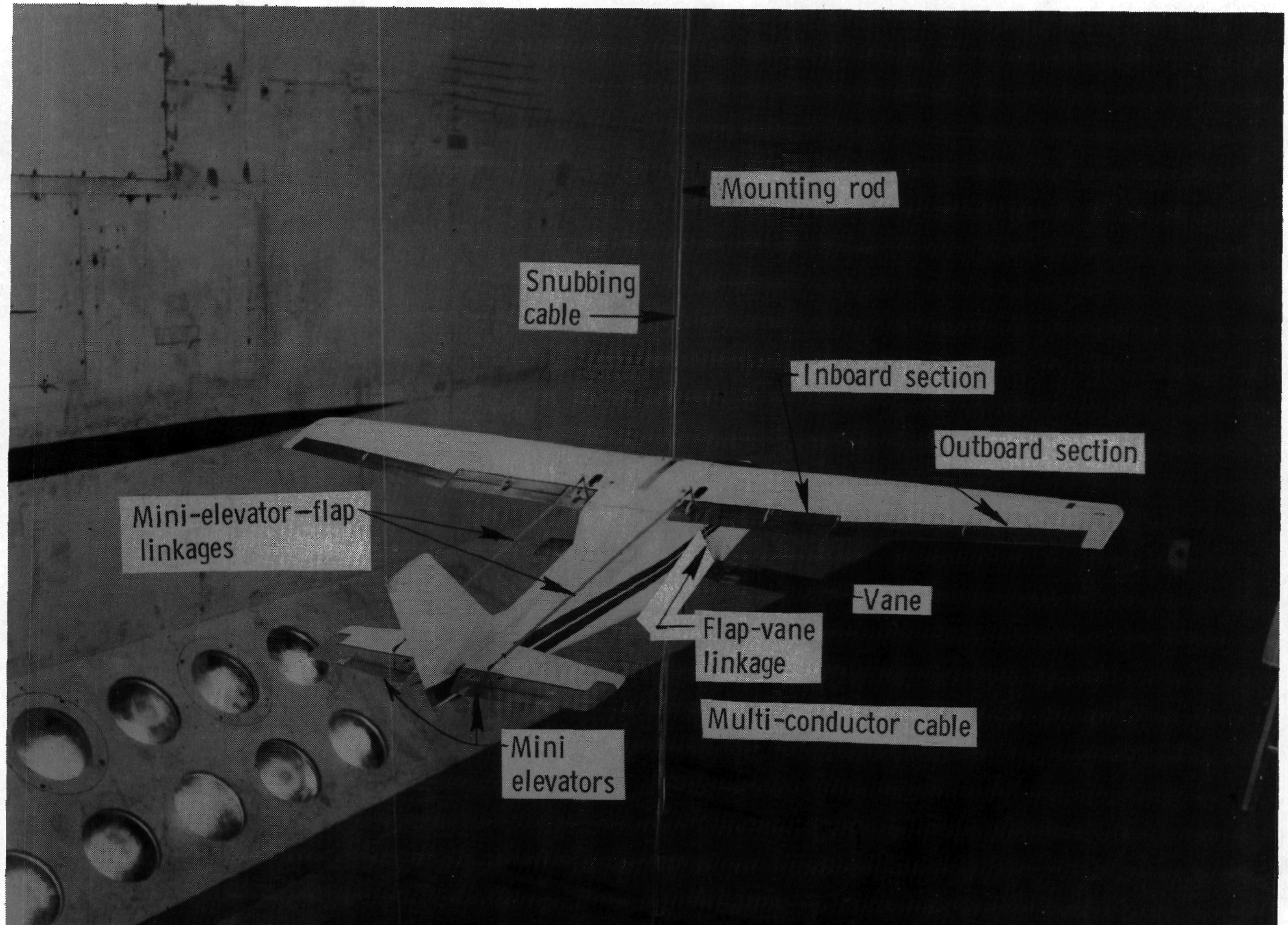


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Figure 2.- Photograph of model mounted in test section with mini-elevators linked to flaps.

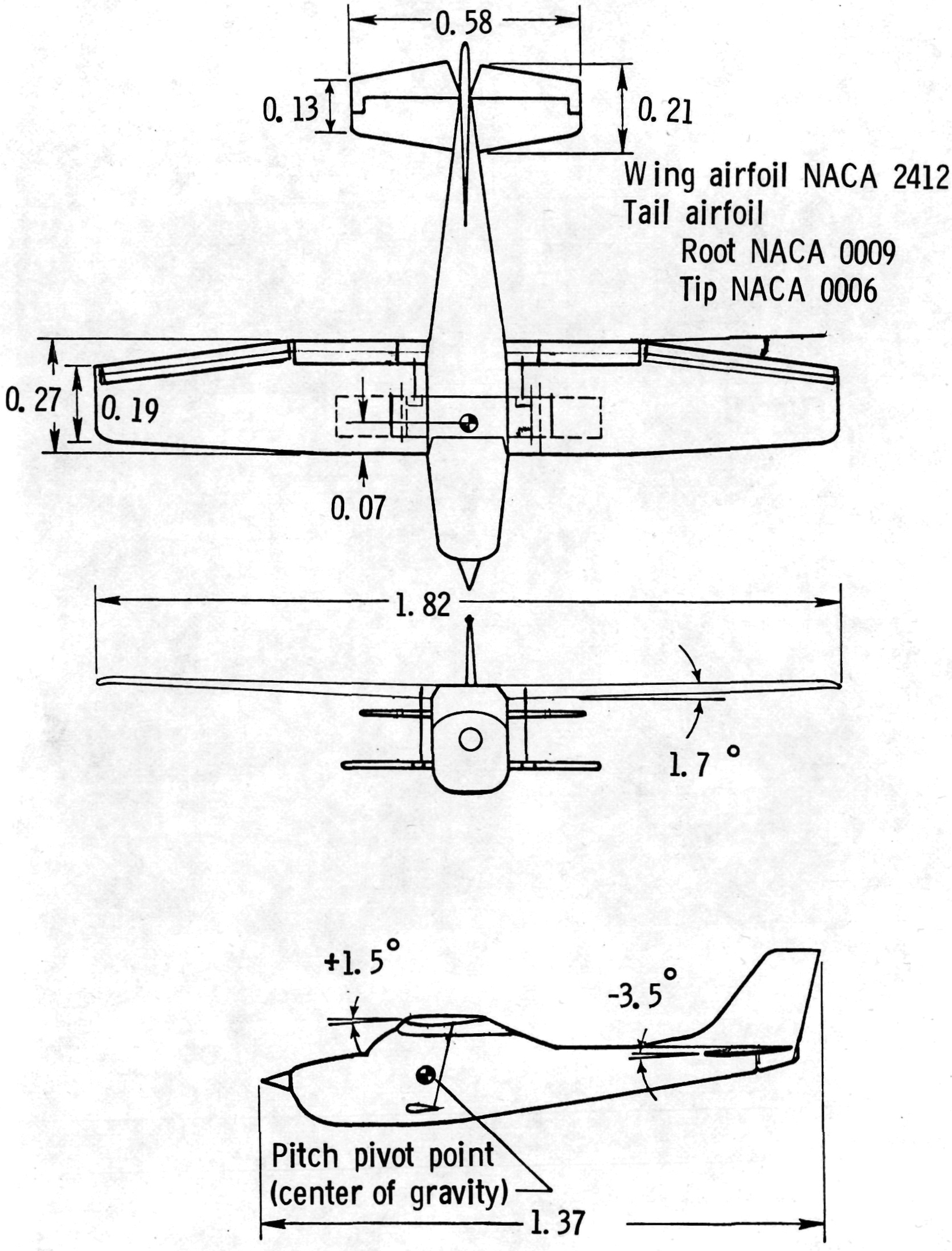

Figure 3.- Three-view drawing of model. All dimensions are in m unless otherwise noted.

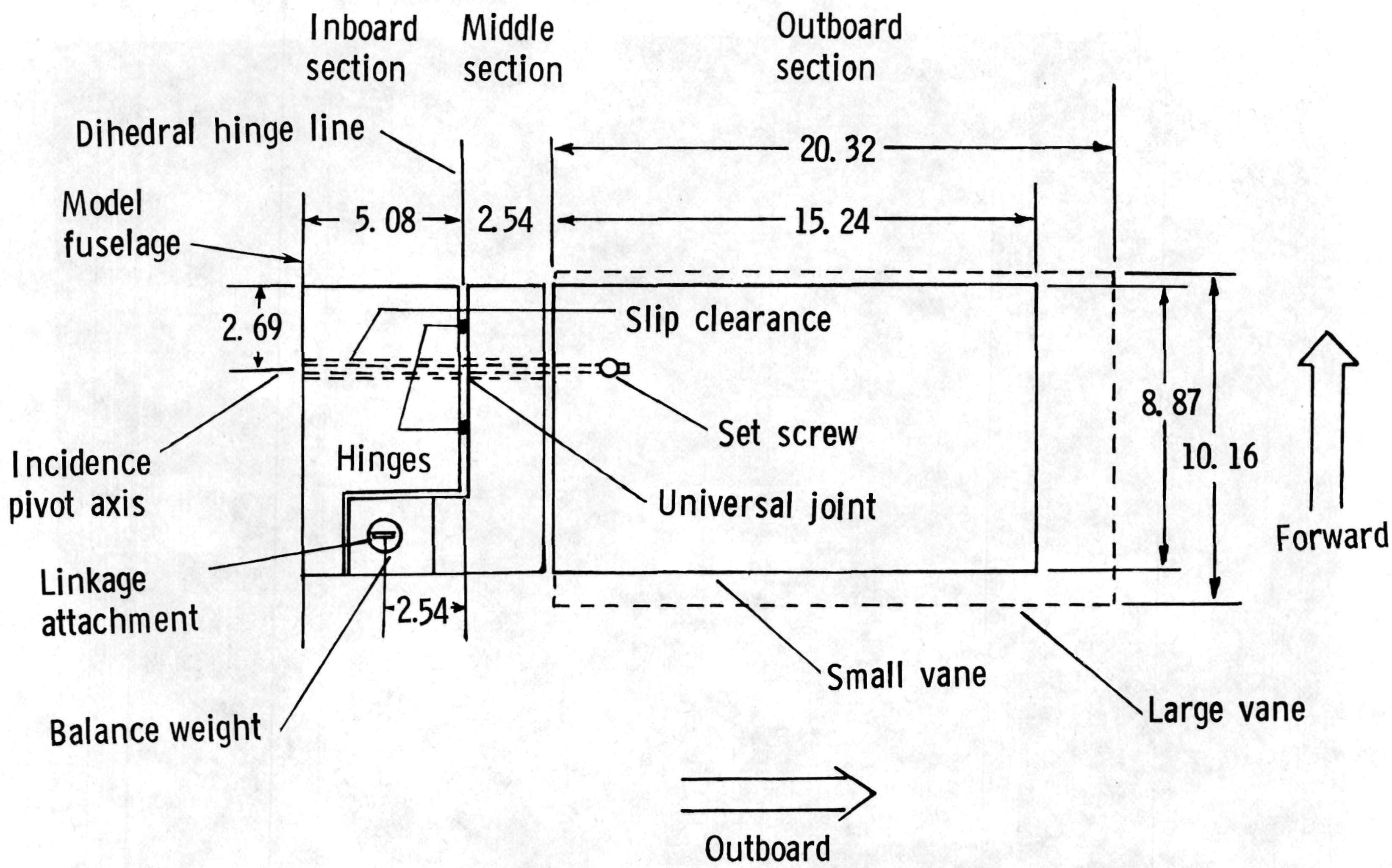

Figure 4.- Detailed view of vane(s). All dimensions are in cm.

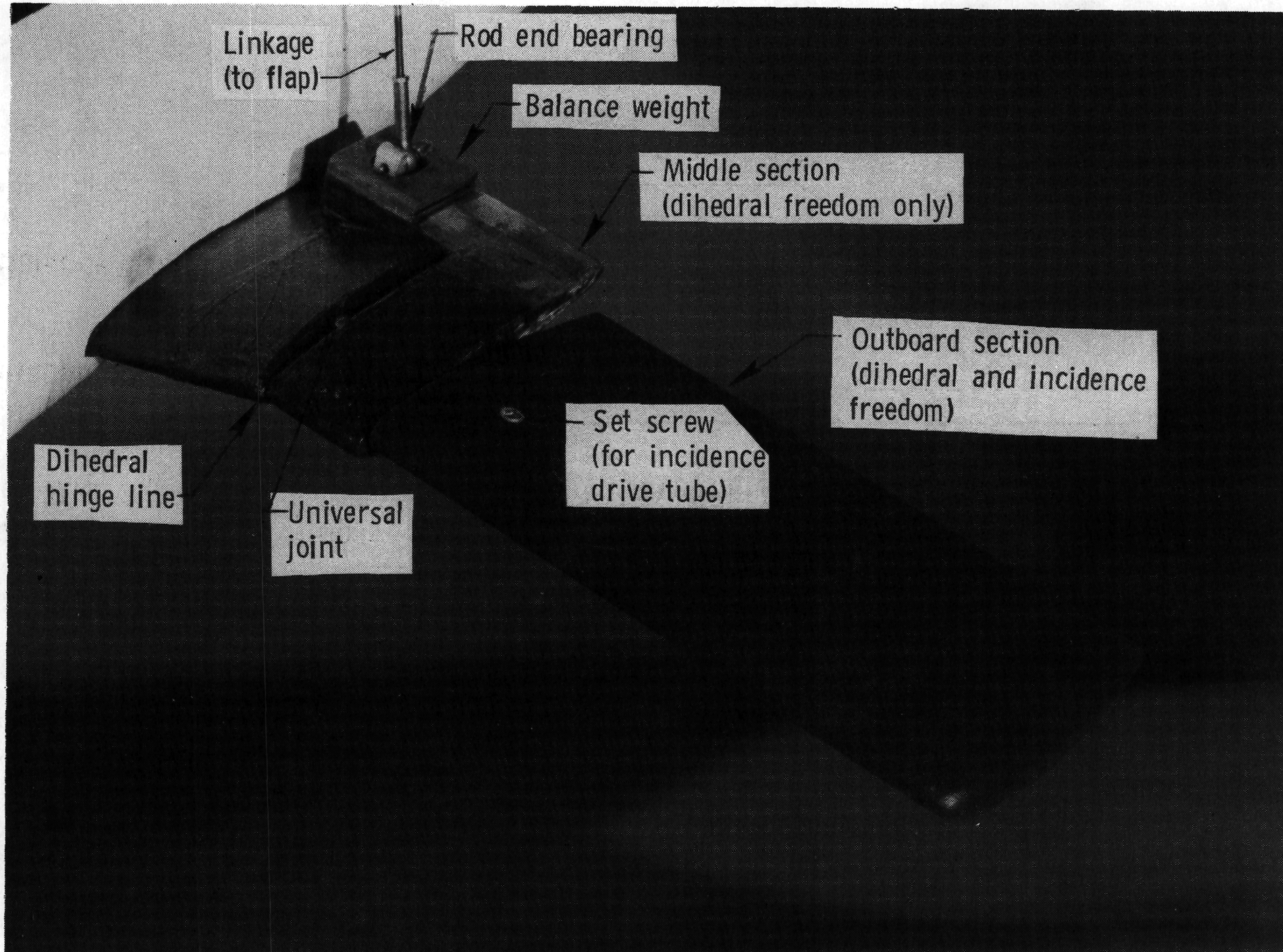

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Figure 5.- Photograph of vane system in deflected position showing dihedral and incidence degrees of freedom.

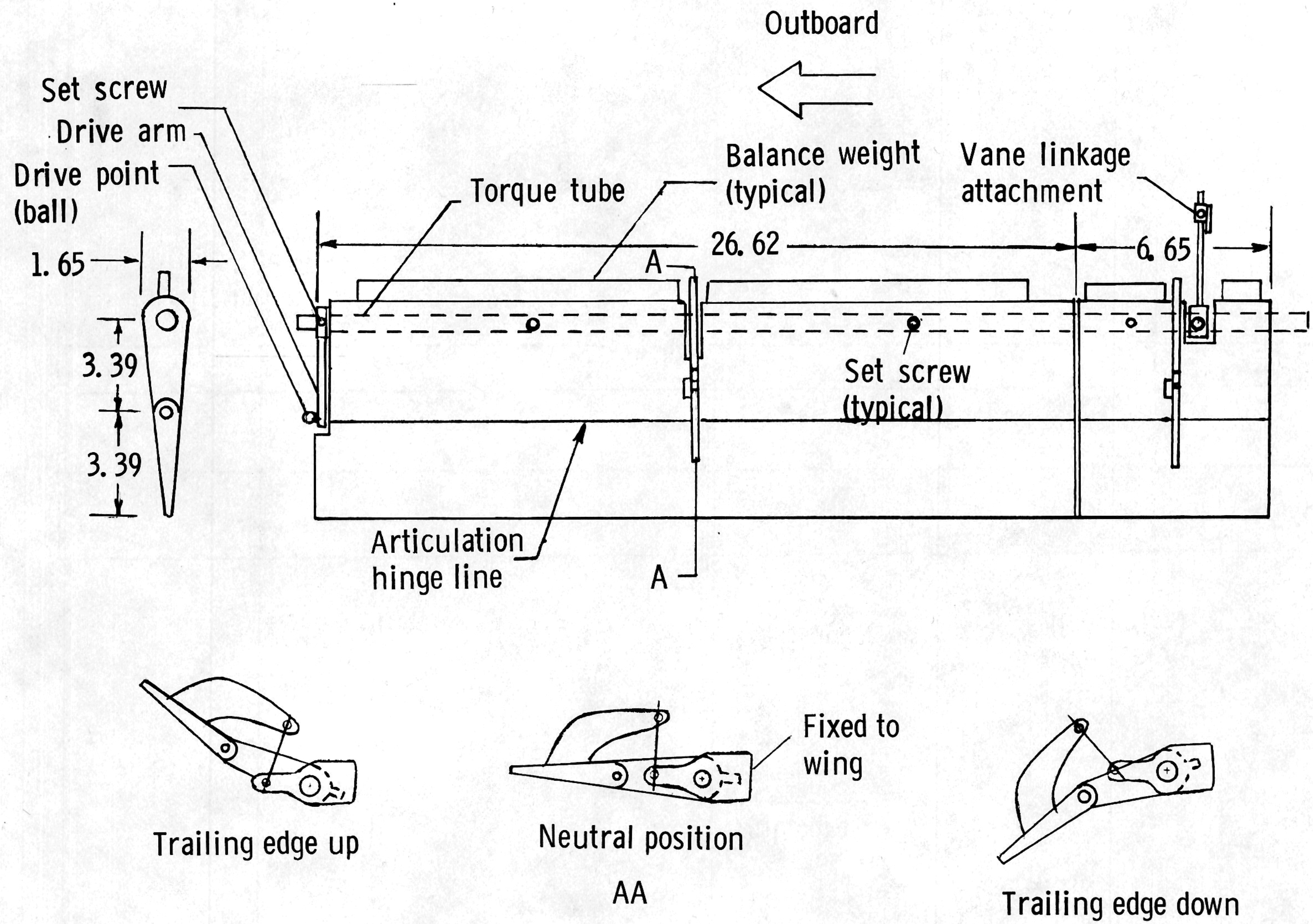

Figure 6.- Detailed view of inboard flap. All dimensions are in cm.

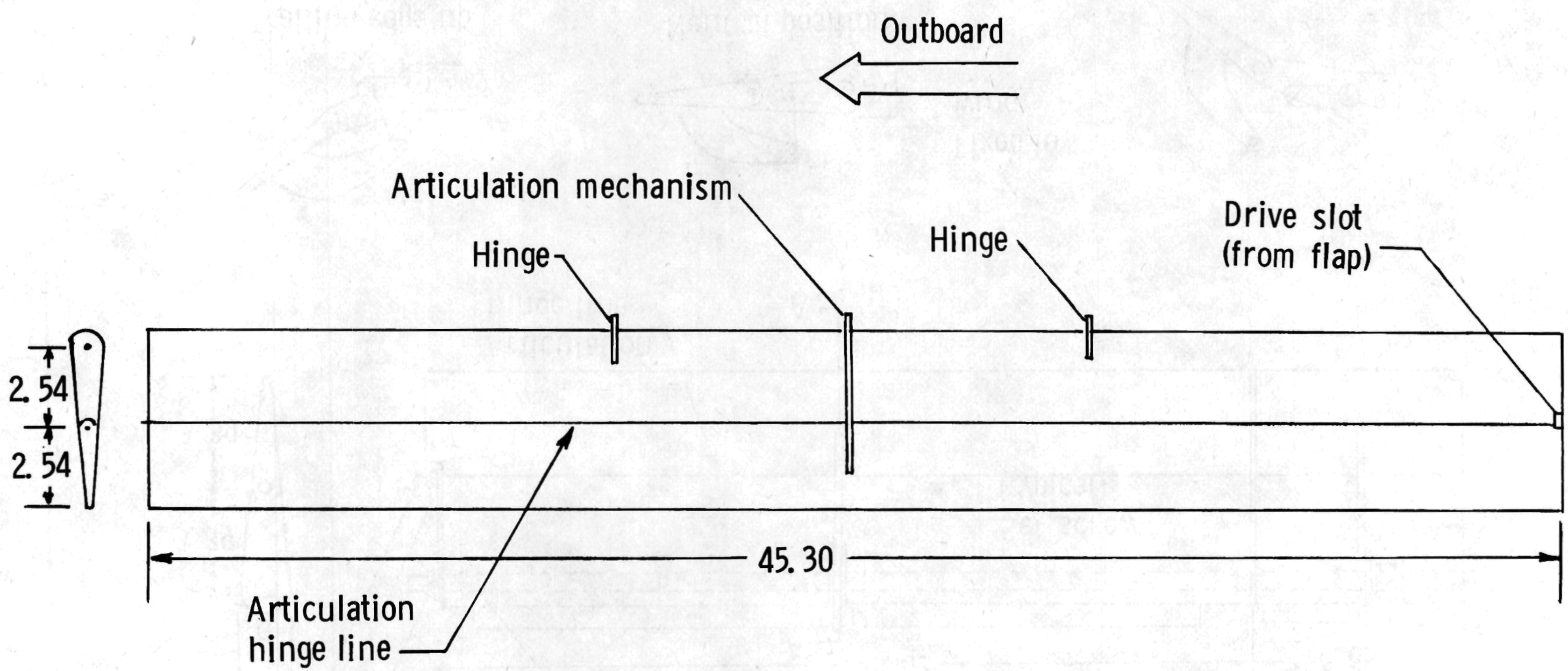

Figure 7.- Detailed view of outboard flap. All dimensions are in cm.

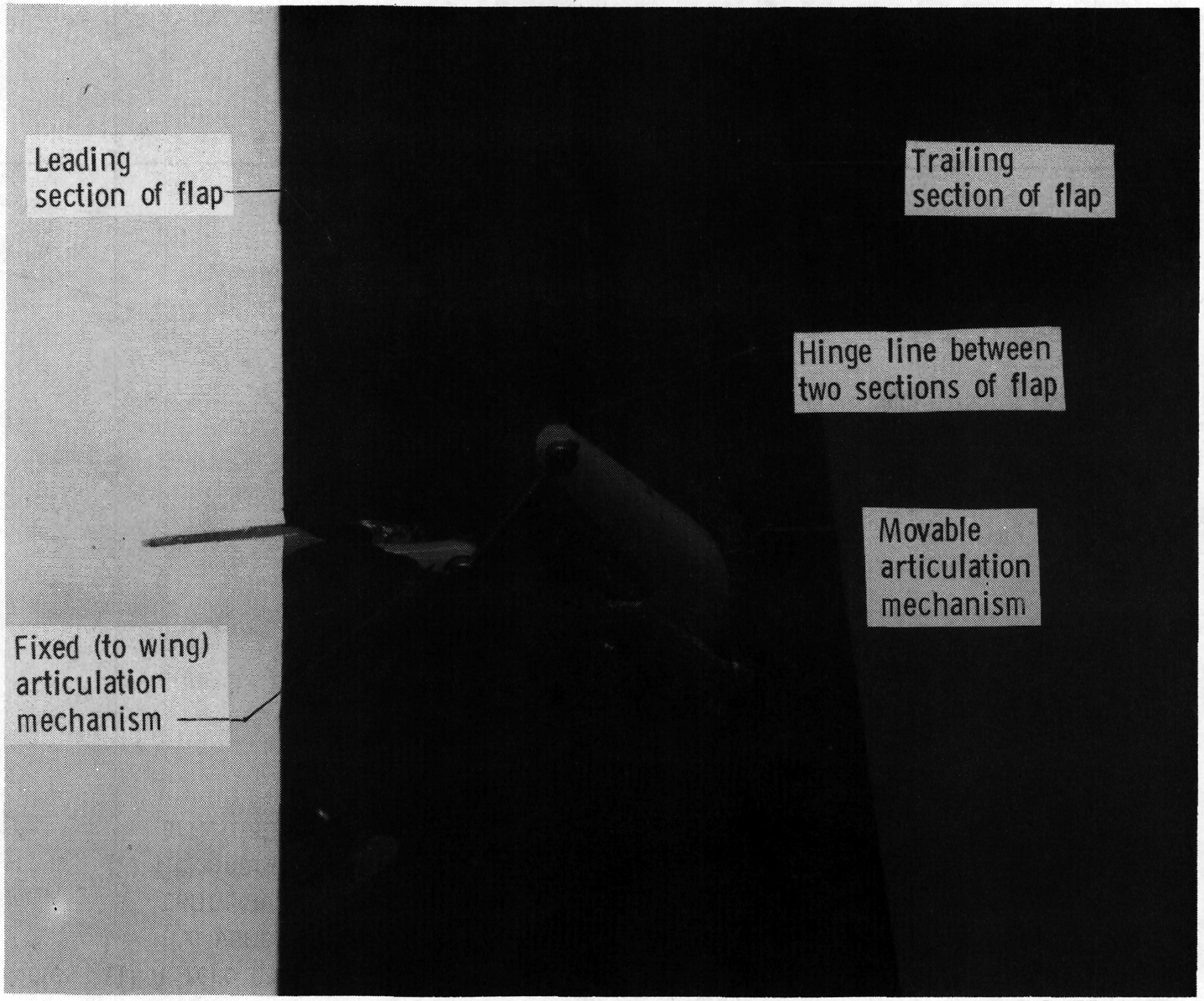

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Figure 8.- Photograph of articulation mechanism.

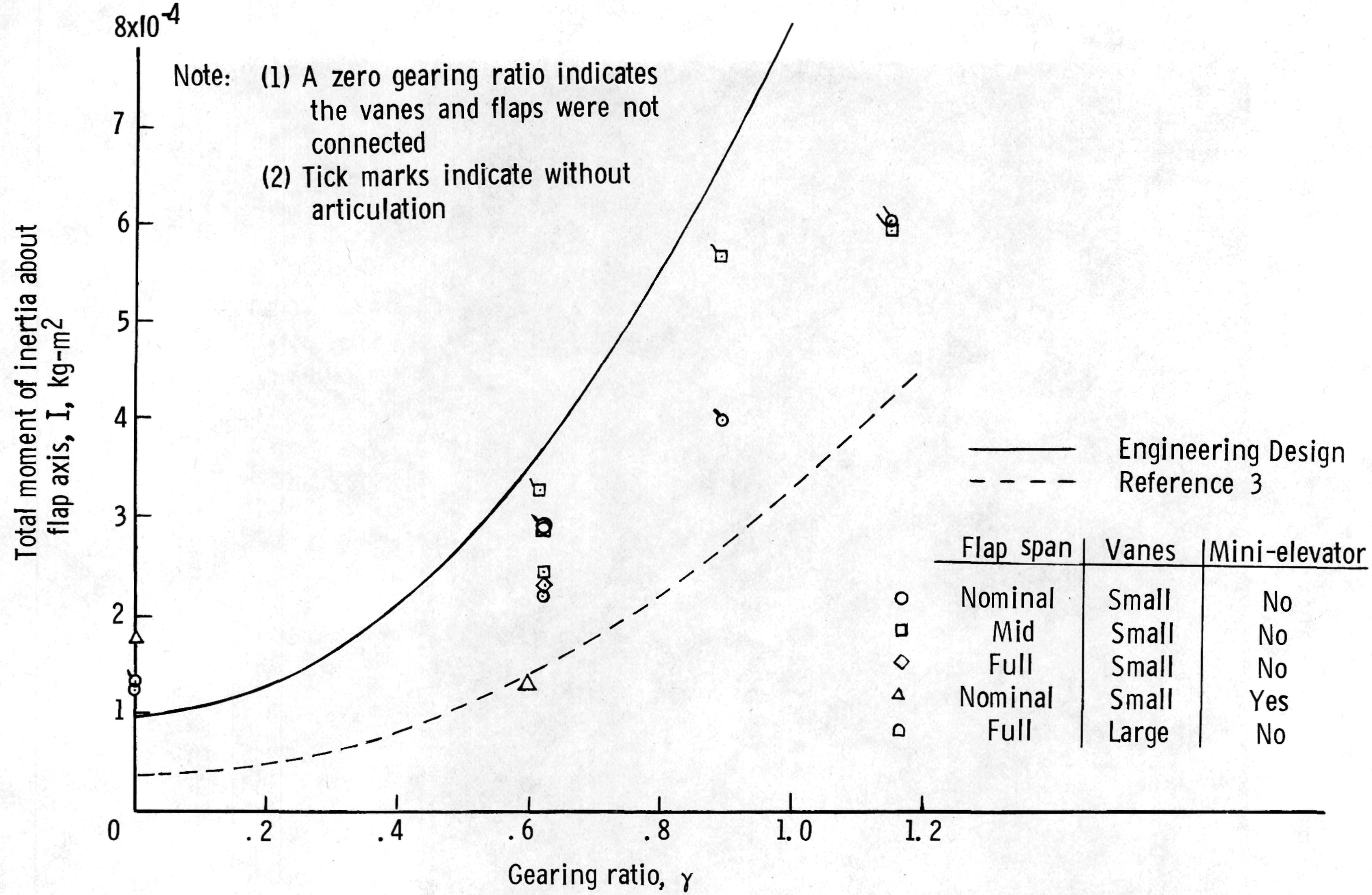


Figure 9.- Total moment of inertia about flap axis as function of gearing ratio.

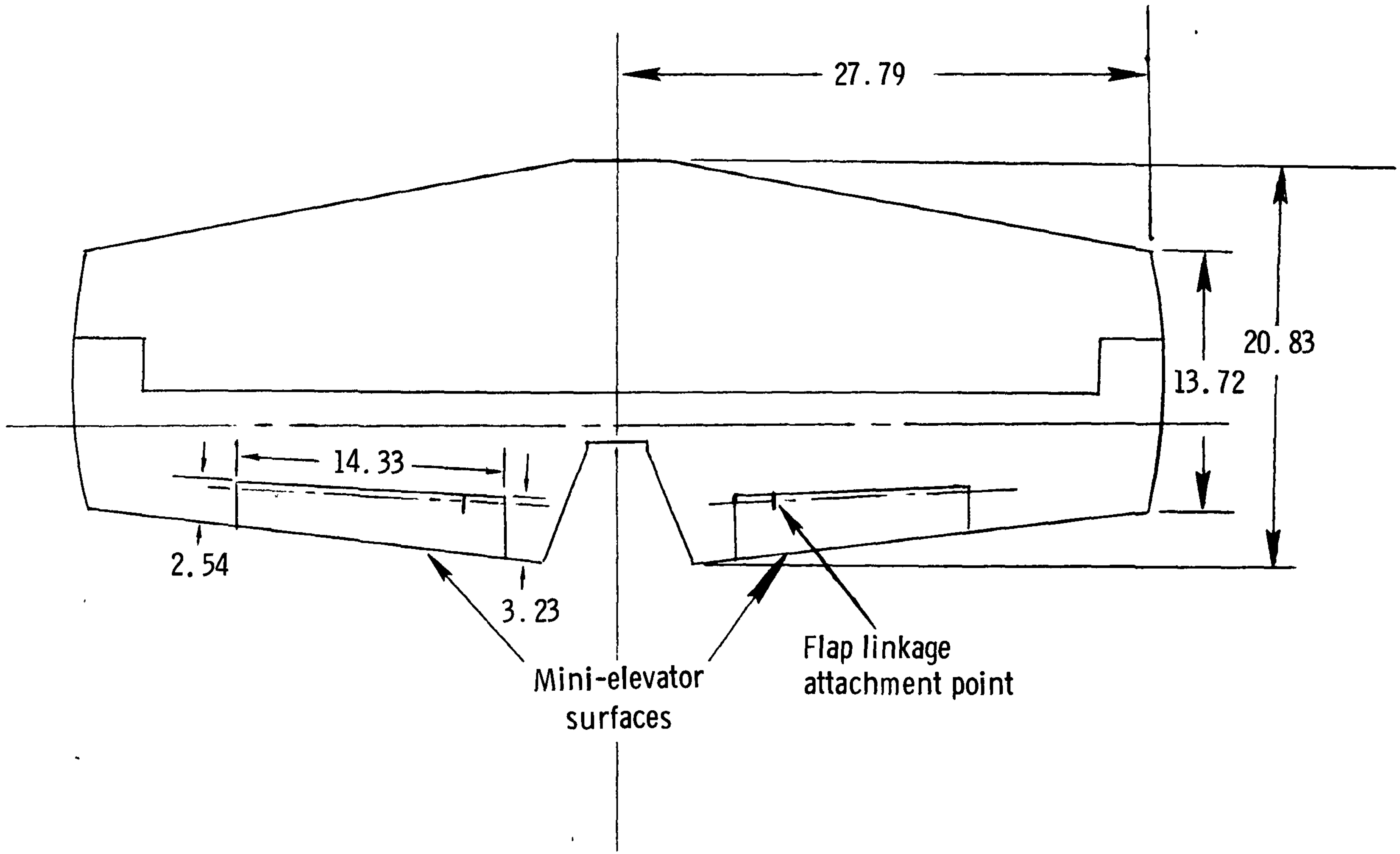


Figure 10.- Mini-elevator configuration. All dimensions are in cm.

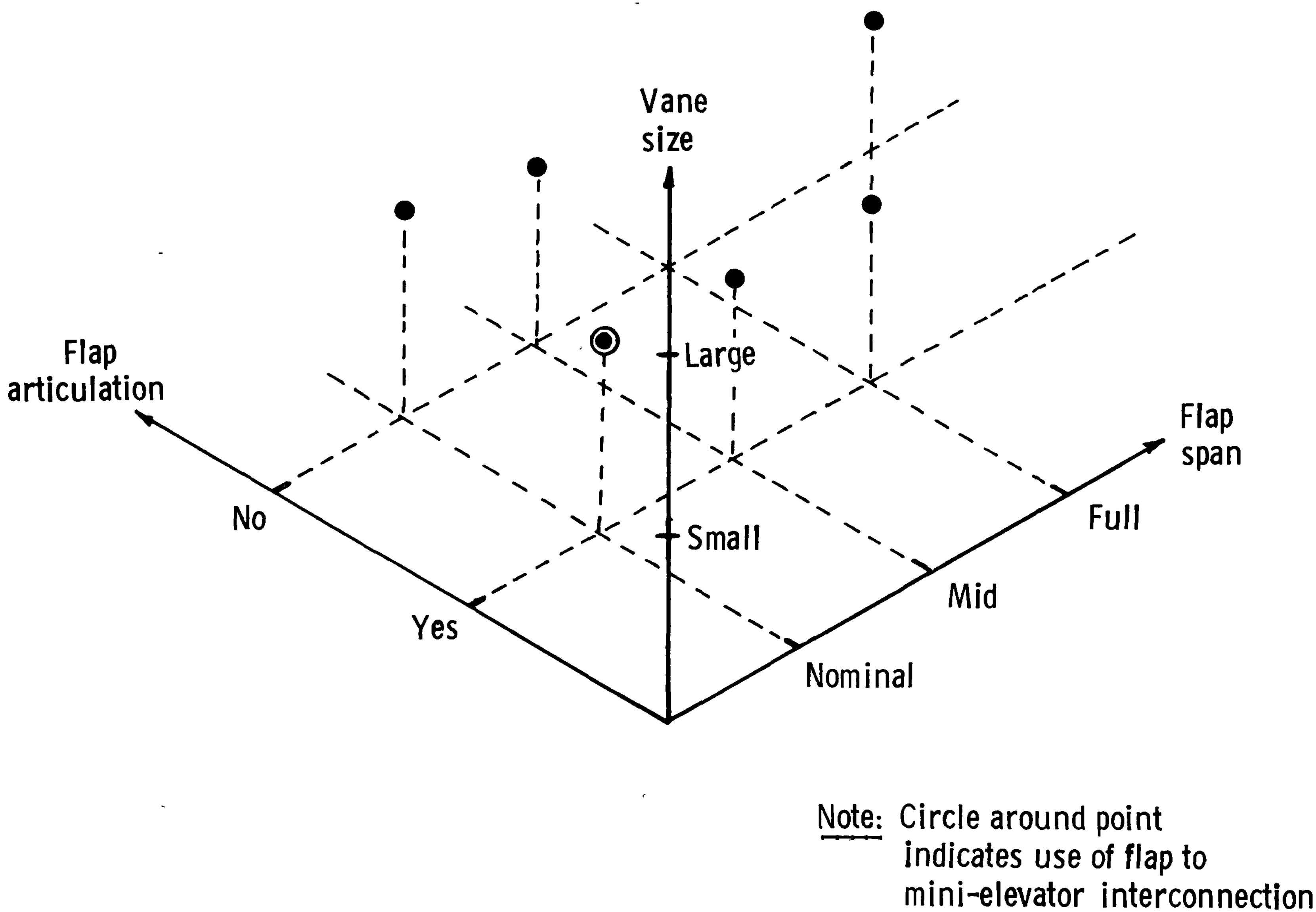


Figure 11.- Isometric pictorial representation of test variable combinations investigated in present tests.

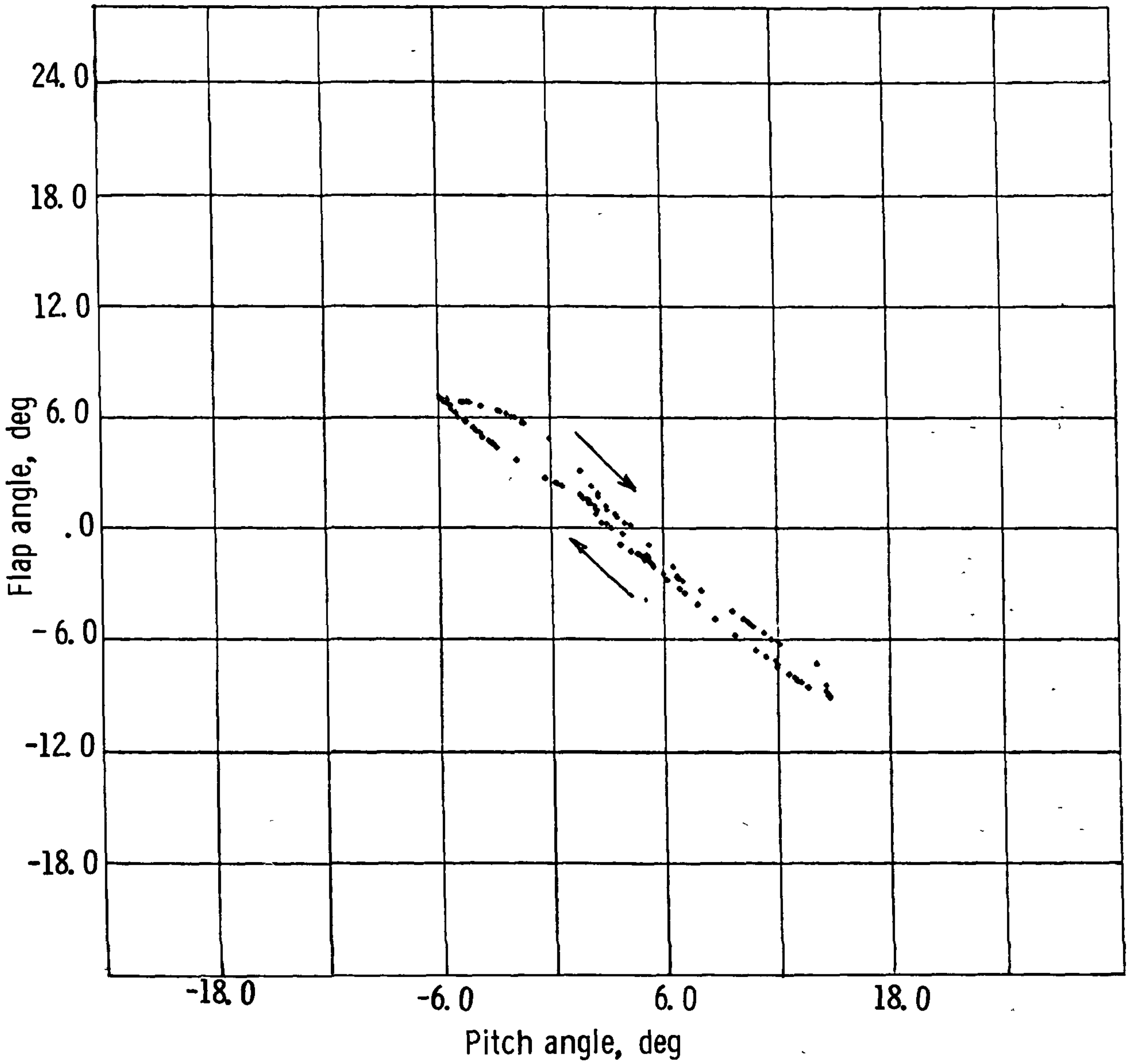


Figure 12.- Typical quasi-static flap response. (Full-span flap; articulation; large vane; gearing ratio = 0.62.) Negative of slope of this plot is flap gain K.

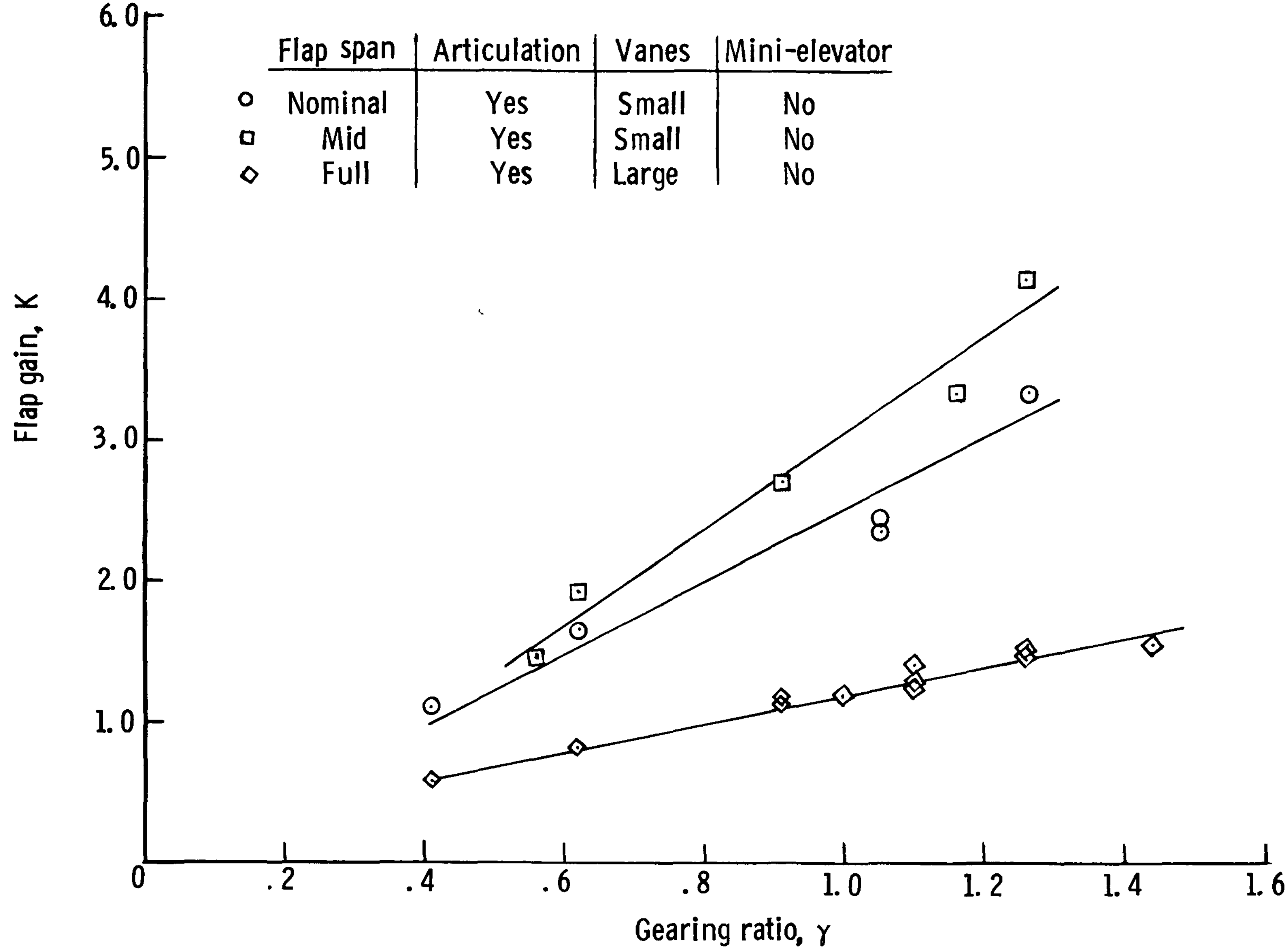


Figure 13.- Flap gain K as function of gearing ratio.

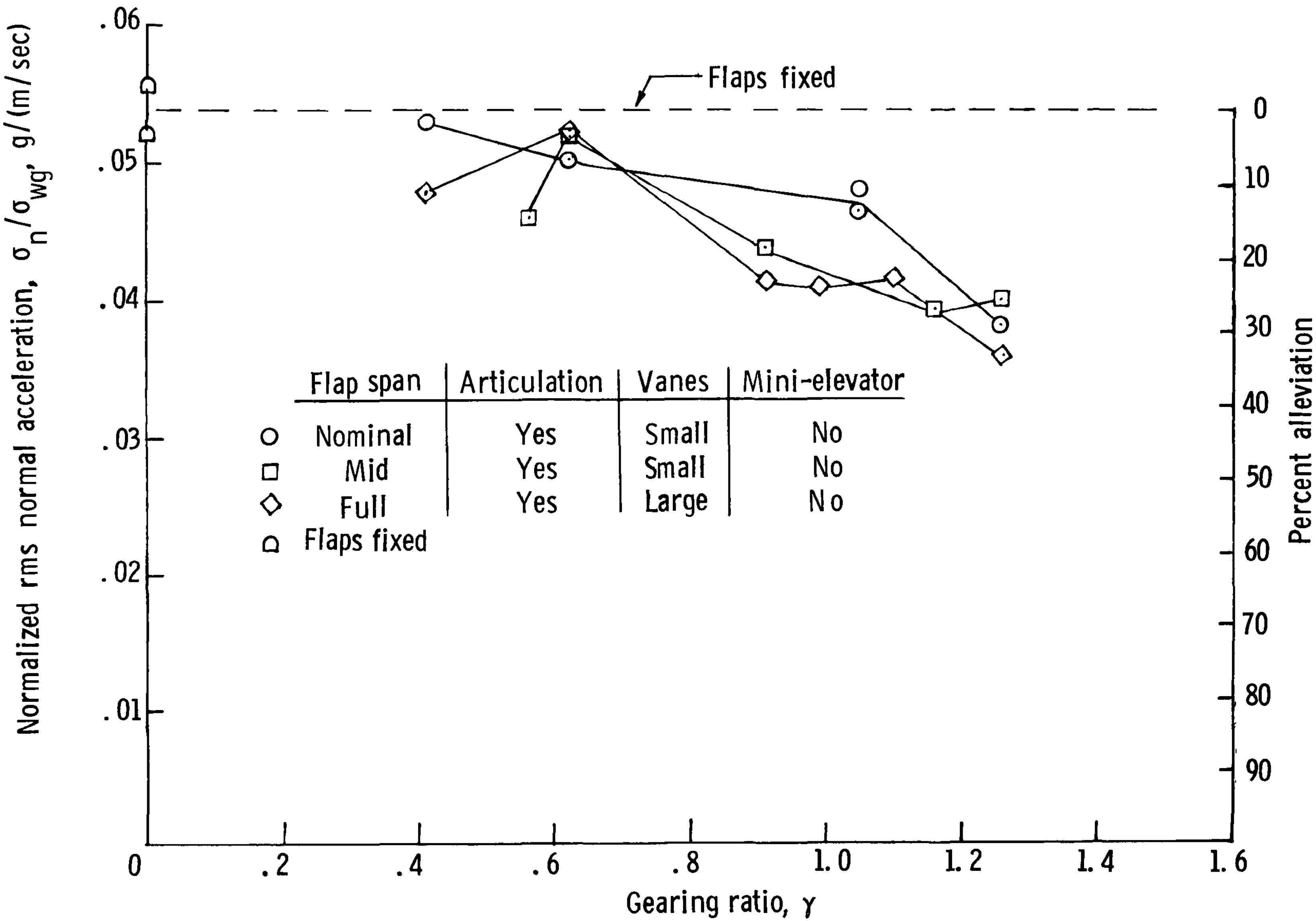
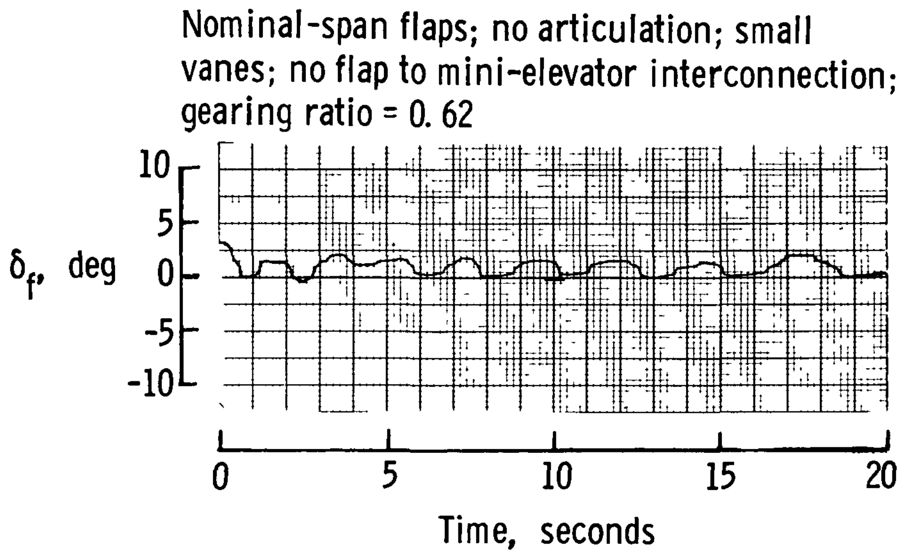
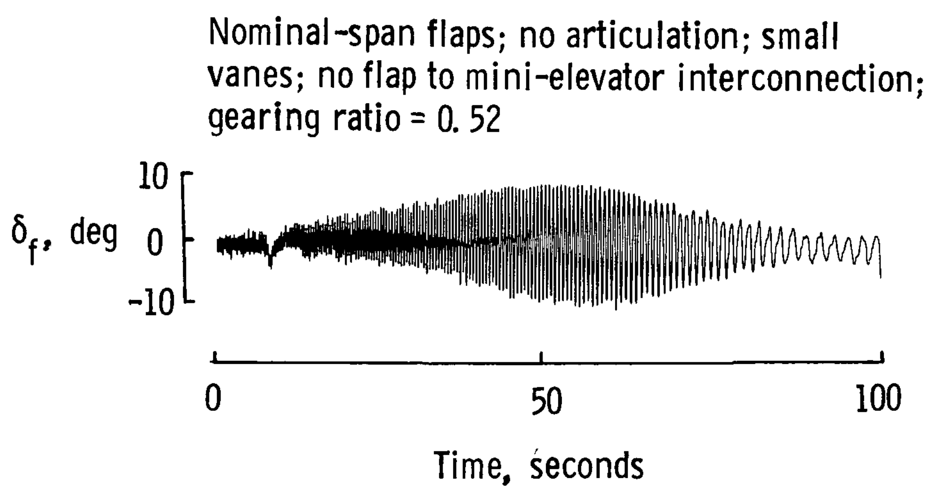


Figure 14.- Effect of flap span on predicted root-mean-square (rms) normal acceleration response for full-scale airplane in atmospheric turbulence based on model measurements.



(a) Flap response (present tests, high friction).



(b) Flap response (ref. 2, low friction).

Figure 15.- Comparison of effects of friction on typical time history response of flap during sinusoidal sweep.

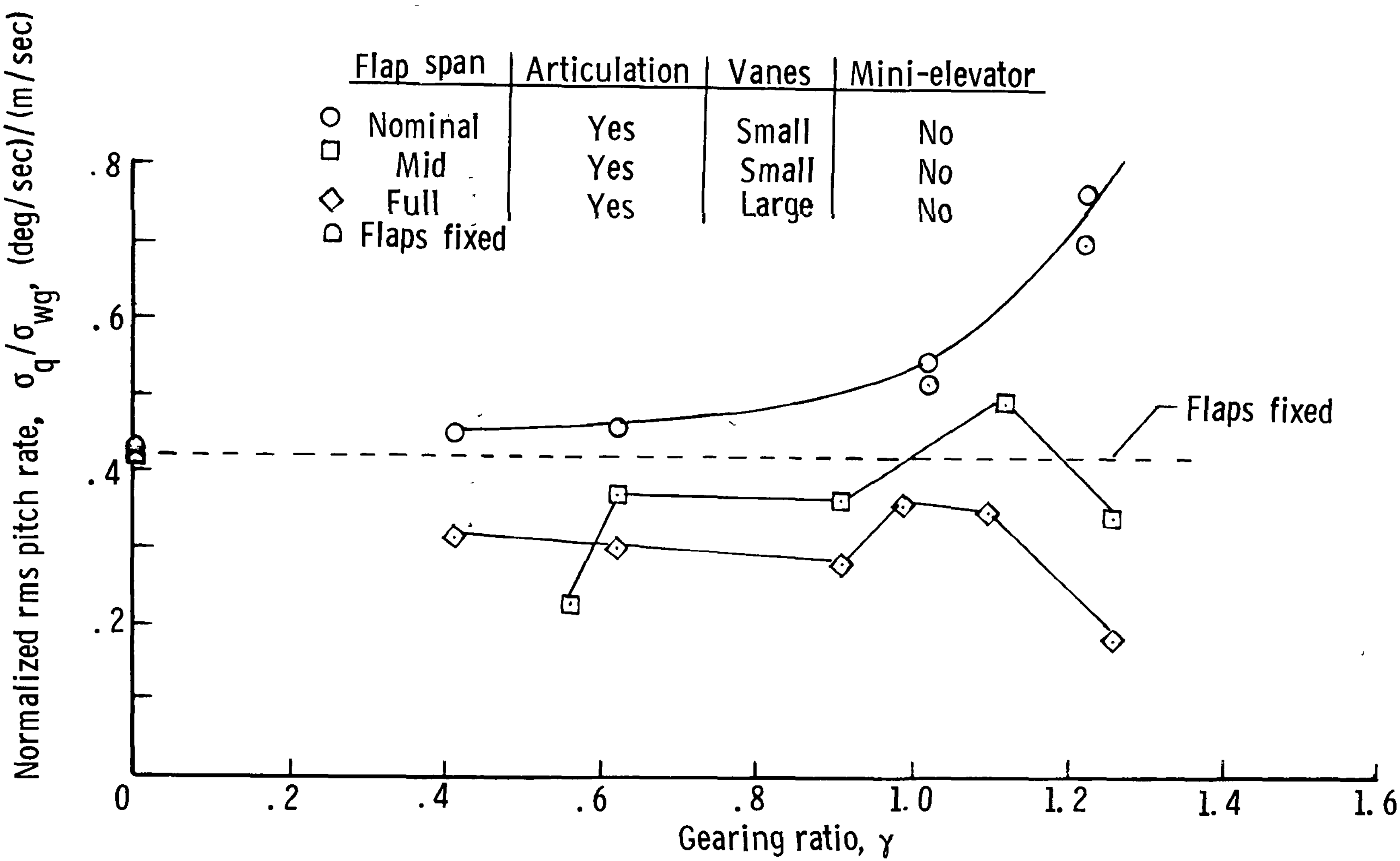


Figure 16.- Effect of flap span on predicted root-mean-square (rms) pitching rate of full-scale airplane in atmospheric turbulence based on model measurements.

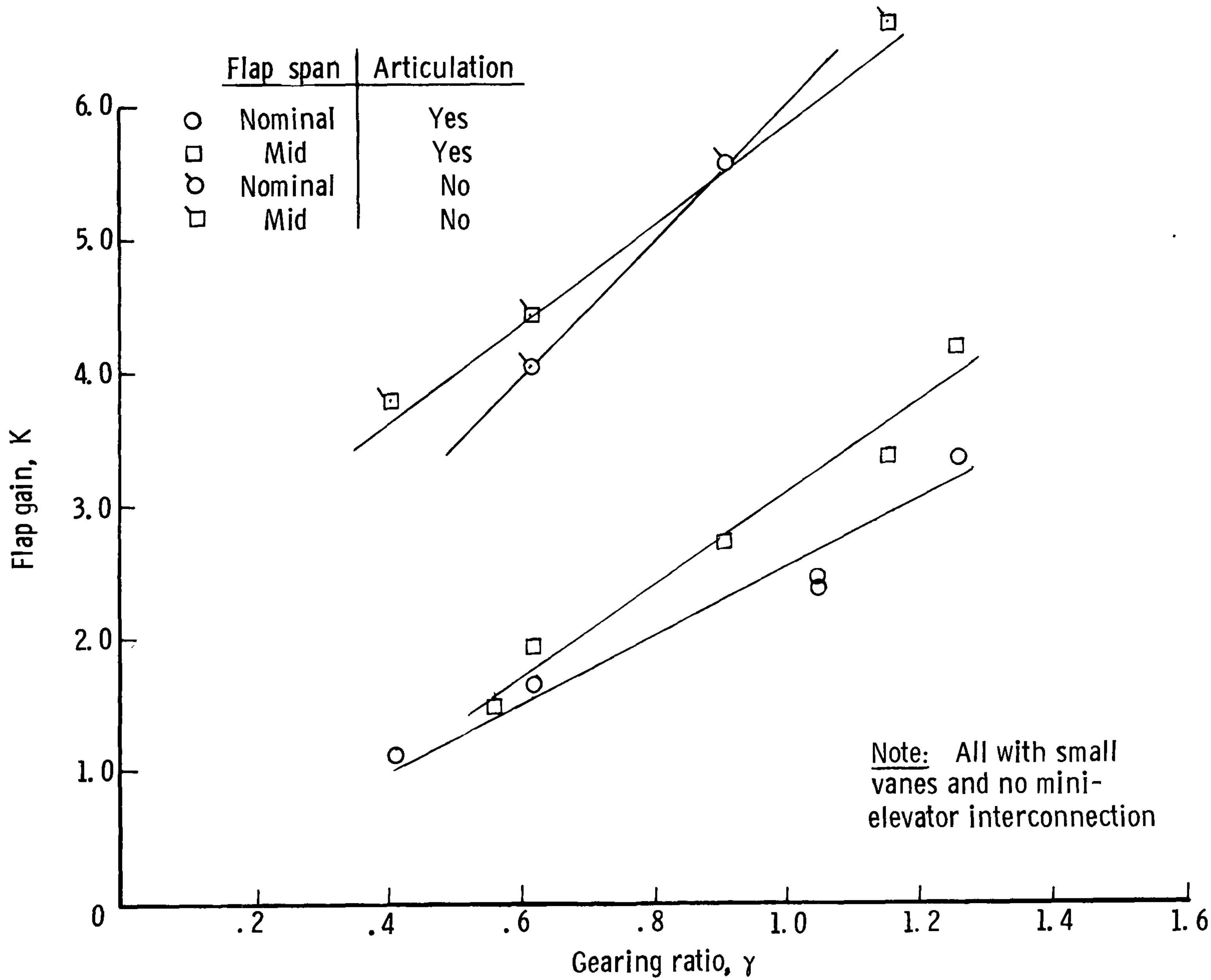


Figure 17.- Effect of articulation on flap gain K.

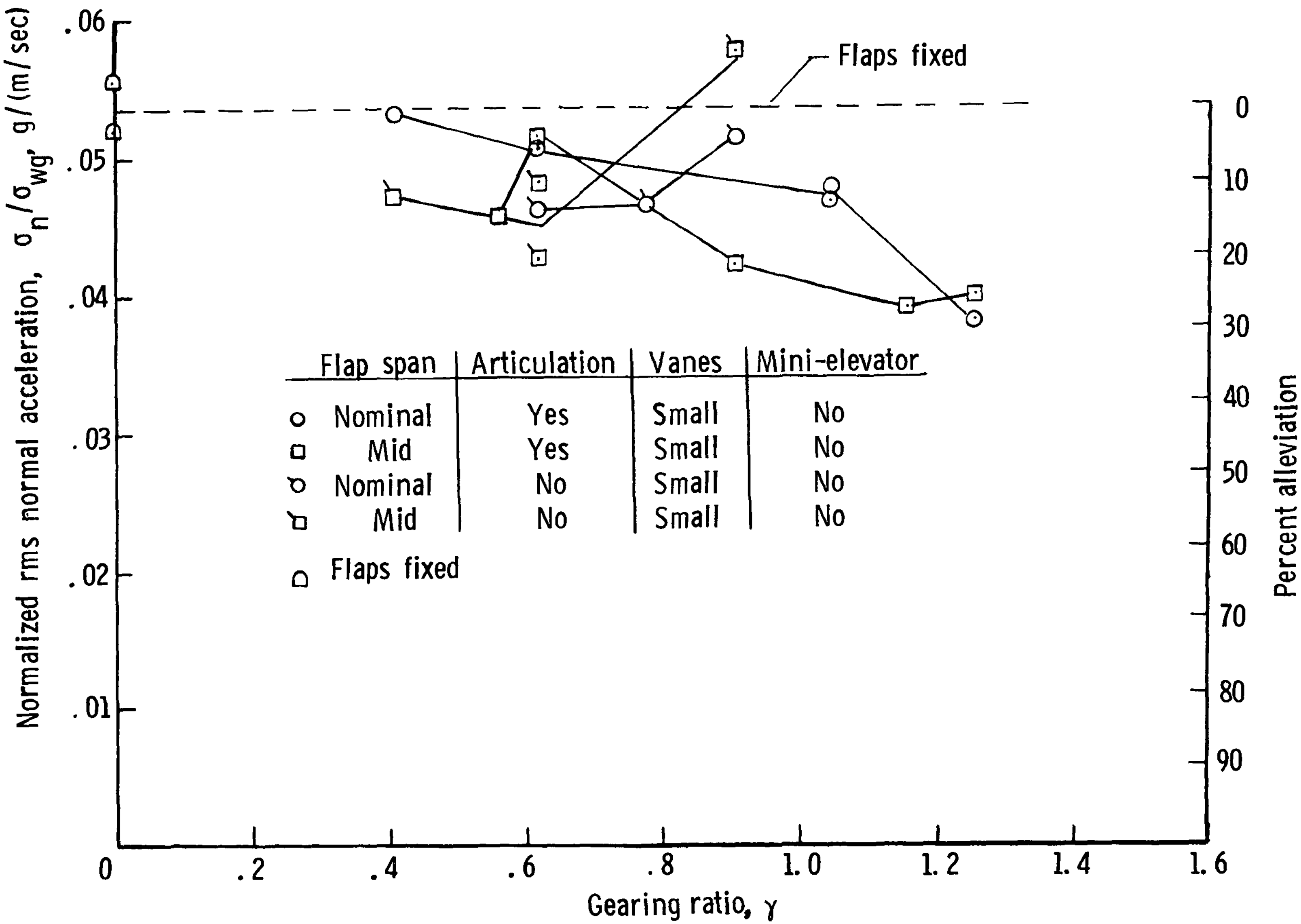


Figure 18.- Effect of articulation on predicted root-mean-square (rms) normal acceleration response for full scale airplane in atmospheric turbulence based on model measurements. (Data points refer to flap spans with and without articulation.)

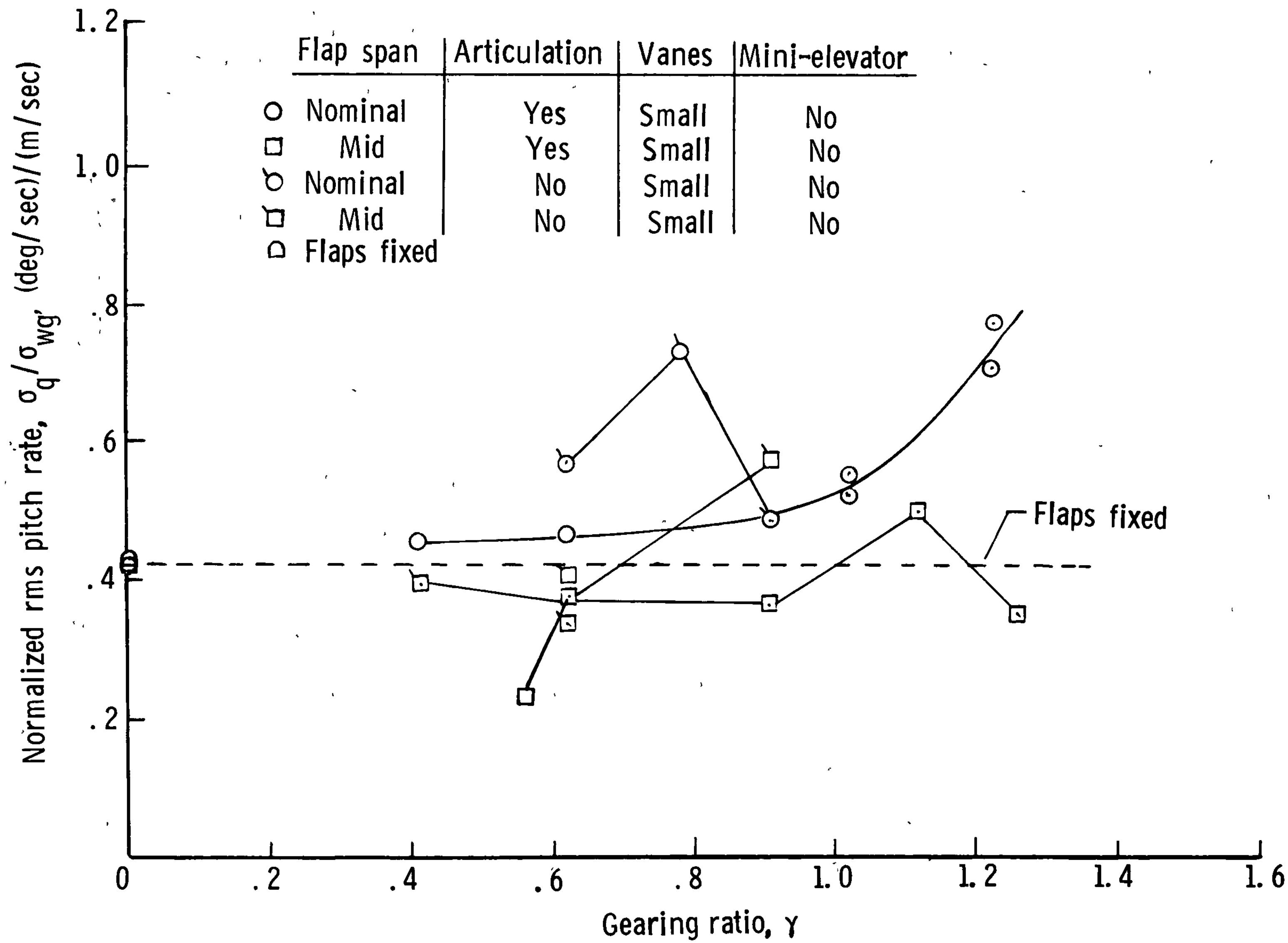


Figure 19.- Effect of articulation on predicted root-mean-square (rms) pitching rate response for full-scale airplane in atmospheric turbulence based on model measurements.

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15 Supplementary Notes

16 Abstract

Some experimental results are presented from wind-tunnel studies of a dynamic model equipped with an aeromechanical gust-alleviation system for reducing the normal acceleration response of light airplanes. The gust-alleviation system consists of two auxiliary aerodynamic surfaces that deflect the wing flaps through mechanical linkages when a gust is encountered to maintain nearly constant airplane lift. The gust-alleviation system was implemented on a 1/6-scale, rod-mounted, free-flying model that is geometrically and dynamically representative of small, four-place, high-wing, single-engine, light airplanes. The effects of flaps with different spans, two sizes of auxiliary aerodynamic surfaces, plain and double-hinged flaps, and a flap-elevator interconnection were studied. The model test results are presented in terms of predicted root-mean-square response of the full scale airplane to atmospheric turbulence. The results show that the gust-alleviation system reduces the root-mean-square normal acceleration response by 30 percent in comparison with the response in the flaps-locked condition. Small reductions in pitch-rate response were obtained also. It is believed that substantially larger reductions in normal acceleration can be achieved by reducing the rather high levels of mechanical friction which were extant in the alleviation system of the present model.

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